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XMUT204 Electronic Design

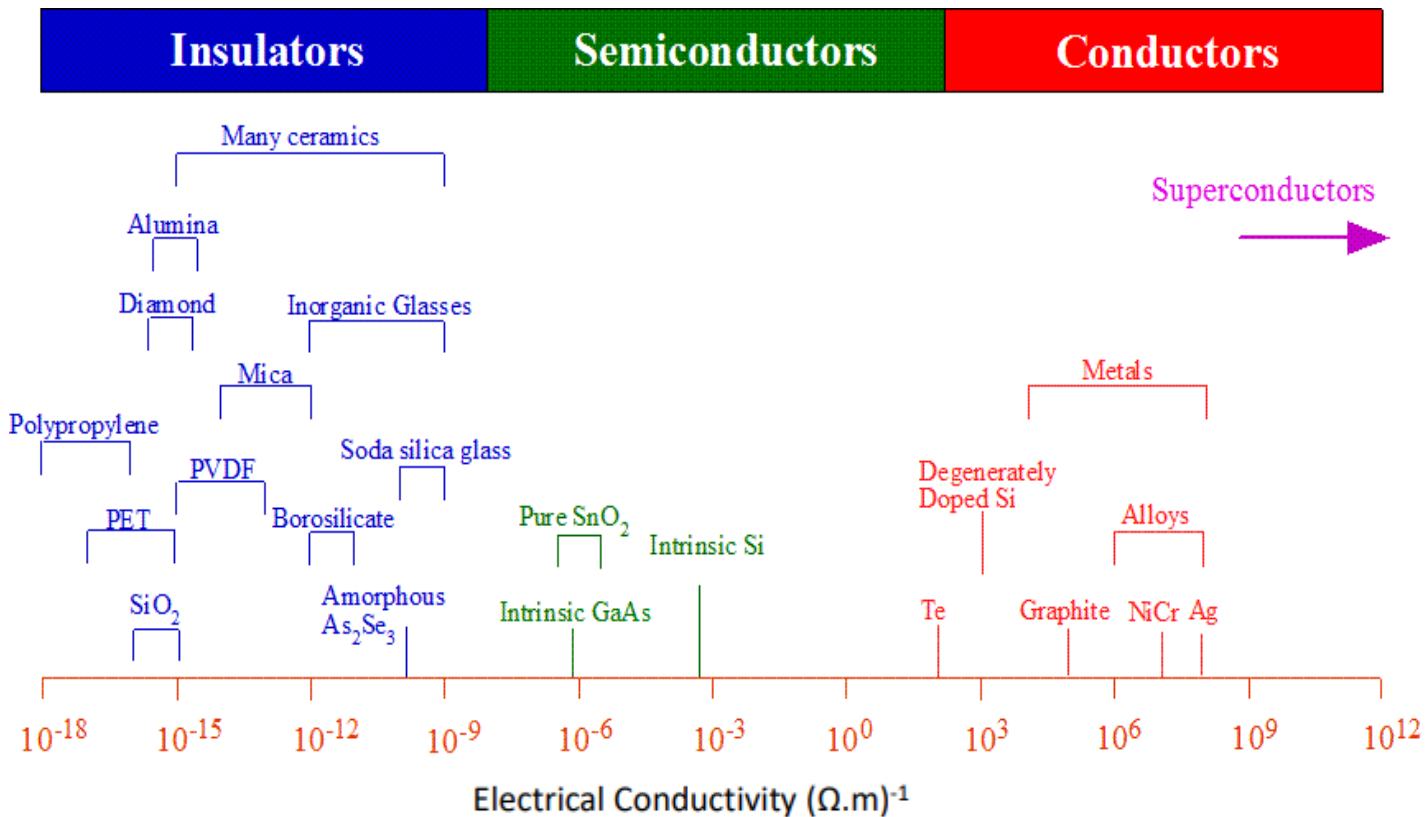
Lecture 1a - Introduction to Semiconductors

Overview

1. Conductivity and resistivity of materials.
2. Characteristics of semiconductor.
3. Lattice structure.
4. Doping of semiconductor materials.

1. Conductivity and Resistivity of Materials

- The conductivities of various materials i.e. insulators, semiconductors and conductors.



1. Conductivity and Resistivity of Materials

- Conductivity coefficient of the materials is calculated from:

$$\sigma = ne\mu$$

Where:

n = number of conduction electrons/cm³.

e = electron charge (1.6×10^{-19}).

μ = mobility of electrons.

- Unit of conductivity coefficient of materials is Siemens per meter (S/m).

1. Conductivity and Resistivity of Materials

- Resistivity coefficient of the materials is the inverse of conductivity coefficient:

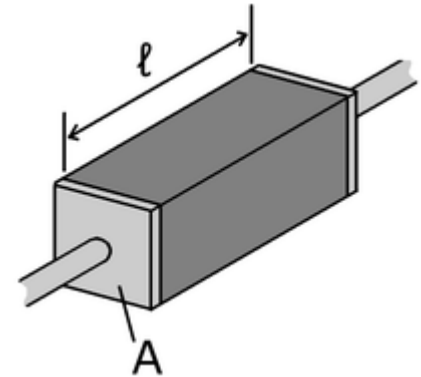
$$\rho = 1/\sigma$$

- Resistance of materials (R) is calculated from:

$$R = \frac{\rho l}{A}$$

Where:

- ρ is resistivity of the material.
 - l is the length of the material.
 - A is the cross-sectional area of the material.
- Units of resistivity of materials is Ohm meter ($\Omega\cdot\text{m}$).



1. Conductivity and Resistivity of Materials

Factors that affect conductivity (and also resistivity) coefficient of materials.

- **Cross-Sectional Area:** If the cross-section of a material is large, it can allow more current to pass through it.
- **Length of the Conductor:** A short conductor allows current to flow at a higher rate than a long conductor.
- **Temperature:** Increasing temperature makes particles vibrate or move more. More of this movement (higher temperature) decreases conductivity because the molecules are more likely to get in the way of current flow. At extremely low temperatures, some materials are superconductors.

1. Conductivity and Resistivity of Materials

- Resistivity and conductivity coefficients of various materials.

Material	Resistivity	Conductivity
C (Graphite)	1.0×10^{-8}	1.0×10^8
Ag	1.6×10^{-8}	6.3×10^7
Cu	1.7×10^{-8}	5.9×10^7
Au	2.4×10^{-8}	4.2×10^7
Al	2.7×10^{-8}	3.7×10^7
Fe	9.7×10^{-8}	1.0×10^7
C (Amorphous)	5.0×10^{-4}	2.0×10^3
Si (Pure)	6.4×10^2	1.6×10^3
Glass (Silica)	1.0×10^{11}	1.0×10^{-11}
C (Diamond)	1.0×10^{12}	1.0×10^{-12}
Teflon	1.0×10^{24}	1.0×10^{-24}

Example for Tutorial 1:

1. What is the resistance of an Aluminium wire that has diameter of 2 mm and length of 10 m?

Note that an Aluminium has resistivity coefficient, $\rho = 2.65 \times 10^{-8} \Omega\text{m}$.

[2.5 marks]

2. Calculate the electrical conductivity of the material of a conductor of length 3 m, area of cross section 0.02 mm^2 having a resistance of 20Ω . [2.5 marks]

1. Resistance of the material, R is calculated from:

$$R = \frac{\rho L}{A} = \frac{L}{\sigma A}$$

Cross sectional area of the round wire (A) with a radius of r is calculated from:

$$A = \pi(r)^2$$

Putting in the values to the equation:

$$R = \frac{(2.65 \times 10^{-8})(10)}{\pi(1 \times 10^{-3})^2} = 8.44 \times 10^{-2} \Omega/\text{m}$$

2. For the given conductor, its resistance is calculated from:

$$R = \frac{\rho l}{A}$$

Rearrange the equation above, the resistivity of the conductor is:

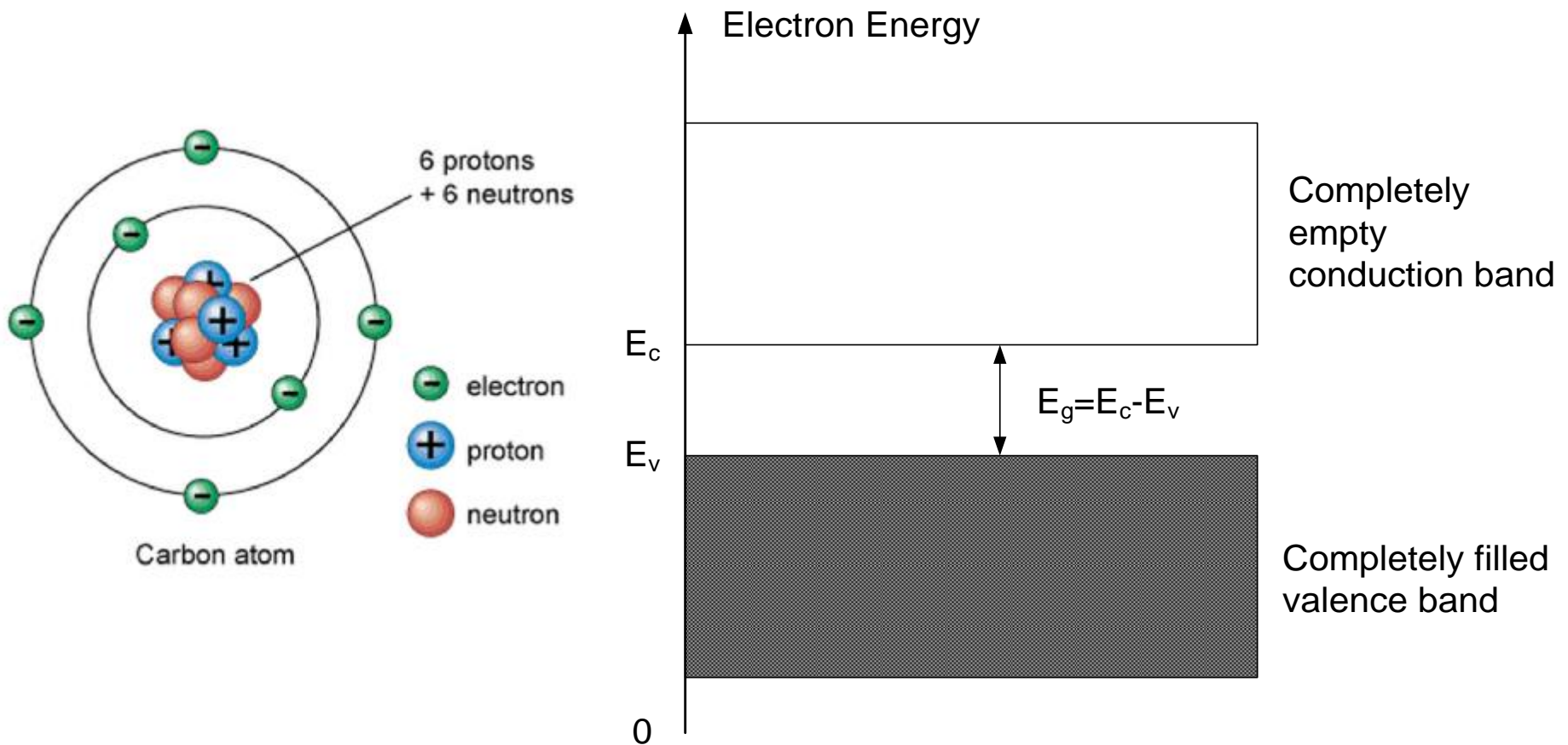
$$\rho = \frac{RA}{l} = \frac{(20)(2 \times 10^{-5})}{3} = 13.33 \times 10^{-5} \Omega\text{m}$$

Since resistivity of the conductor ρ is $13.33 \times 10^{-5} \Omega\text{m}$, the electrical conductivity of the conductor is:

$$\sigma = \frac{1}{\rho} = \frac{1}{13.33 \times 10^{-5}} = 0.075 \text{ S/m}$$

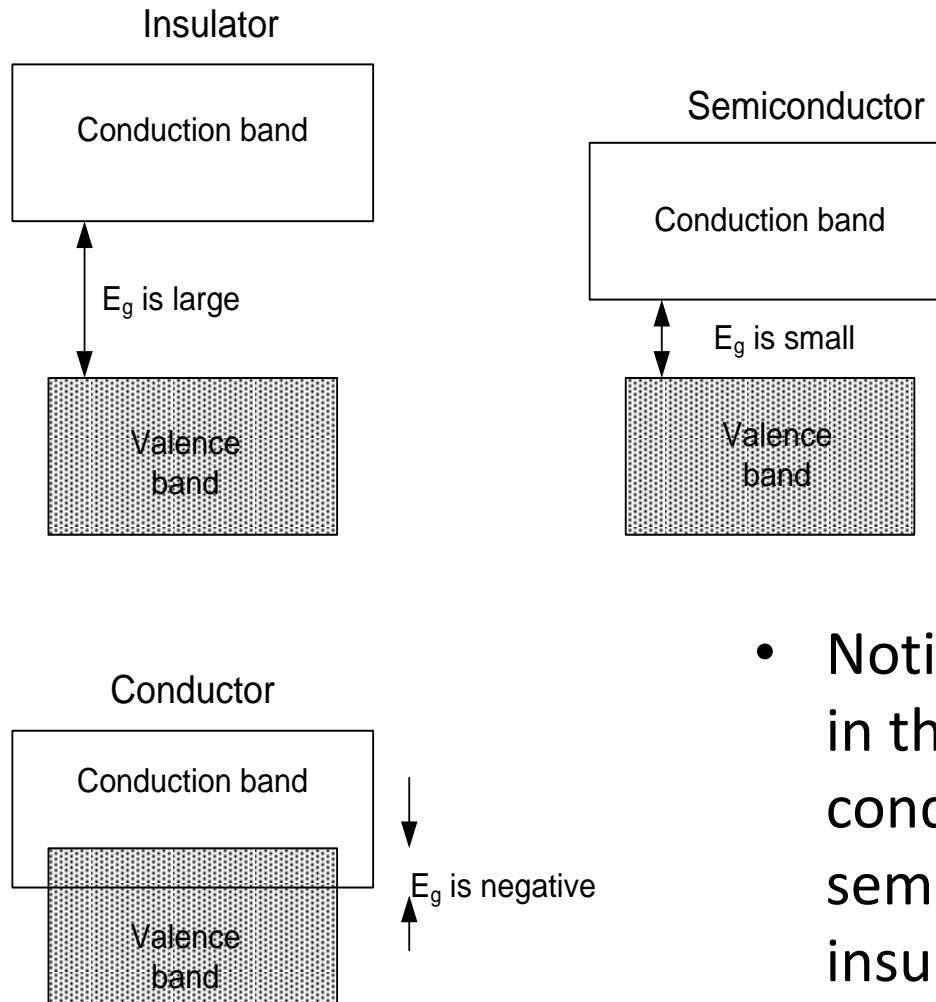
2. Characteristics of Semiconductor

- The electron energy band structure of a solid material.



2. Characteristics of Semiconductor

- Energy band structure of various materials.



- Notice the differences in the gap band of conductors, semiconductors and insulators materials.

2. Characteristics of Semiconductor

The Periodic Table of the Elements

1																		18		
Hydrogen 1 H 1.01	2																	Helium 2 He 4.00		
		<div><div></div><div>Alkali metals</div></div>																		
		<div><div></div><div>Alkaline earth metals</div></div>																		
		<div><div></div><div>Transition metals</div></div>																		
		<div><div></div><div>Other metals</div></div>																		
		<div><div></div><div>Metalloids (semi-metal)</div></div>																		
		<div><div></div><div>Nonmetals</div></div>																		
		<div><div></div><div>Halogens</div></div>																		
		<div><div></div><div>Noble gases</div></div>																		
Lithium 3 Li 6.94	Berilium 4 Be 9.01																	Neon 10 Ne 20.18		
Sodium 11 Na 22.99	Magnesium 12 Mg 24.31																	Argon 18 Ar 39.95		
Potassium 19 K 39.10	Calcium 20 Ca 40.08	Scandium 21 Sc 44.96	Titanium 22 Ti 47.88	Vanadium 23 V 50.94	Chromium 24 Cr 52.00	Manganese 25 Mn 54.94	Iron 26 Fe 55.85	Cobalt 27 Co 58.93	Nickel 28 Ni 58.69	Copper 29 Cu 63.55	Zinc 30 Zn 65.39	Gallium 31 Ga 69.72	Germanium 32 Ge 72.61	Arsenic 33 As 74.92	Selenium 34 Se 78.96	Bromine 35 Br 79.90	Krypton 36 Kr 83.80			
Rubidium 37 Rb 85.47	Strontium 38 Sr 87.62	Yttrium 39 Y 88.91	Zirconium 40 Zr 91.22	Niobium 41 Nb 92.91	Molybdenum 42 Mo 95.94	Technetium 43 Tc (98)	Ruthenium 44 Ru 101.07	Rhodium 45 Rh 106.42	Palladium 46 Pd 107.87	Silver 47 Ag 107.87	Cadmium 48 Cd 112.41	Indium 49 In 114.82	Tin 50 Sn 118.71	Antimony 51 Sb 121.76	Tellurium 52 Te 127.60	Iodine 53 I 126.90	Xenon 54 Xe 131.29			
Cesium 55 Cs 132.91	Barium 56 Ba 137.33	57-70 x	Lutetium 71 Lu 174.97	Hafnium 72 Hf 178.49	Tantalum 73 Ta 180.95	Tungsten 74 W 183.84	Rhenium 75 Re 186.21	Osmium 76 Os 190.23	Iridium 77 Ir 192.22	Platinum 78 Pt 195.08	Gold 79 Au 196.97	Mercury 80 Hg 200.59	Thallium 81 Tl 204.38	Lead 82 Pb 207.20	Bismuth 83 Bi 208.98	Polonium 84 Po (209)	Astatine 85 At (210)	Radon 86 Rn (222)		
Francium 87 Fr (223)	Radium 88 Ra (226)	89-102 x	Lawrencium 103 Lr (262)	Rutherfordium 104 Rf (267)	Dubnium 105 Db (268)	Seaborgium 106 Sg (271)	Bohrium 107 Bh (272)	Hassium 108 Hs (270)	Meitnerium 109 Mt (276)	Darmstadtium 110 Ds (281)	Roentgenium 111 Rg (280)	Copernicium 112 Cn (285)	Nihonium 113 Nh (284)	Flerovium 114 Fl (289)	Moscovium 115 Uu (288)	Livermorium 116 Uuh (293)	Ununseptium 117 Uus (294)	Unbihexium 118 Uuo (294)		

*lanthanides

57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04
89 Ac (227)	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)

**actinides

- Semiconductor materials as shown in the periodic table

5 B 10.81	6 C 12.01	7 N 14.01
13 Al 26.98	14 Si 28.09	15 P 30.97
31 Ga 69.72	32 Ge 72.61	33 As 74.92
49 In 114.82	50 Sn 118.71	51 Sb 121.76
81 Tl 204.38	82 Pb 207.20	83 Bi 208.98

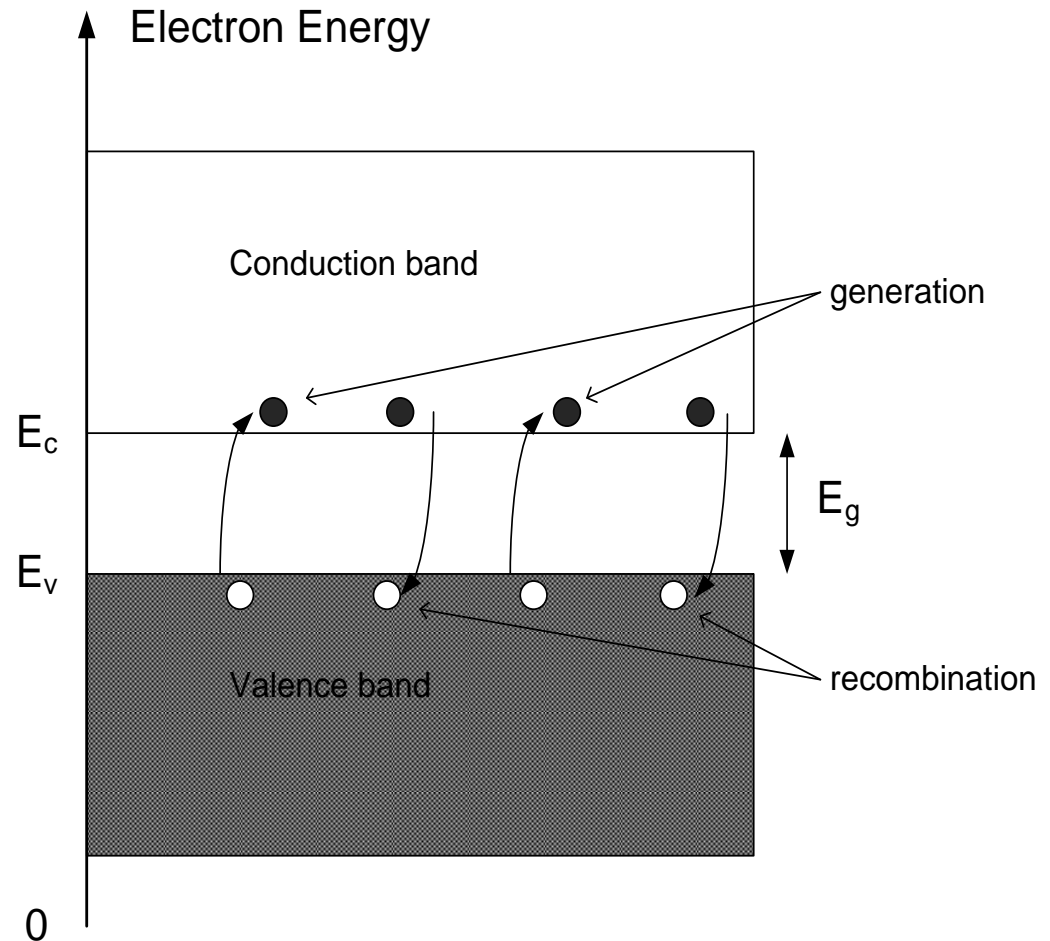
2. Characteristics of Semiconductor

- Chemical characteristics of various semiconductor materials of the first five elements down Group 14 of the periodic table.

Element	Atomic Number	E_g (eV)	Classification	Bonding
C (Diamond)	6	5.5	Insulator	Covalent
Si	14	1.1	Semiconductor	Covalent
Ge	32	0.7	Semiconductor	Covalent
Sn	50	0 (-)	Conductor	Metallic
Pb	82	0 (-)	Conductor	Metallic

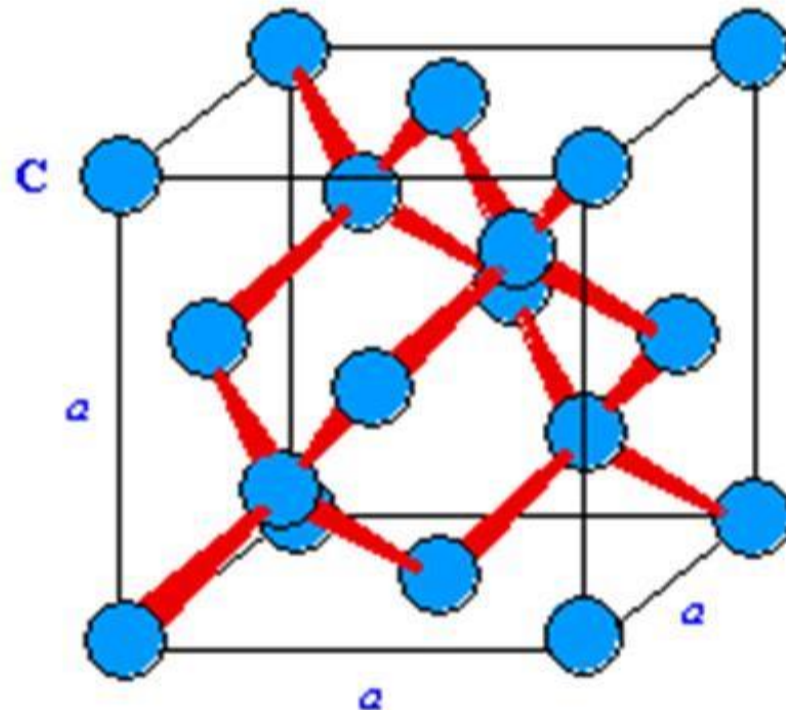
2. Characteristics of Semiconductor

- Electron – hole generation happen due to excitation.
- Nearby electron – hole pair can perform recombination.
- Electron – hole generation and recombination can happen at the same time.

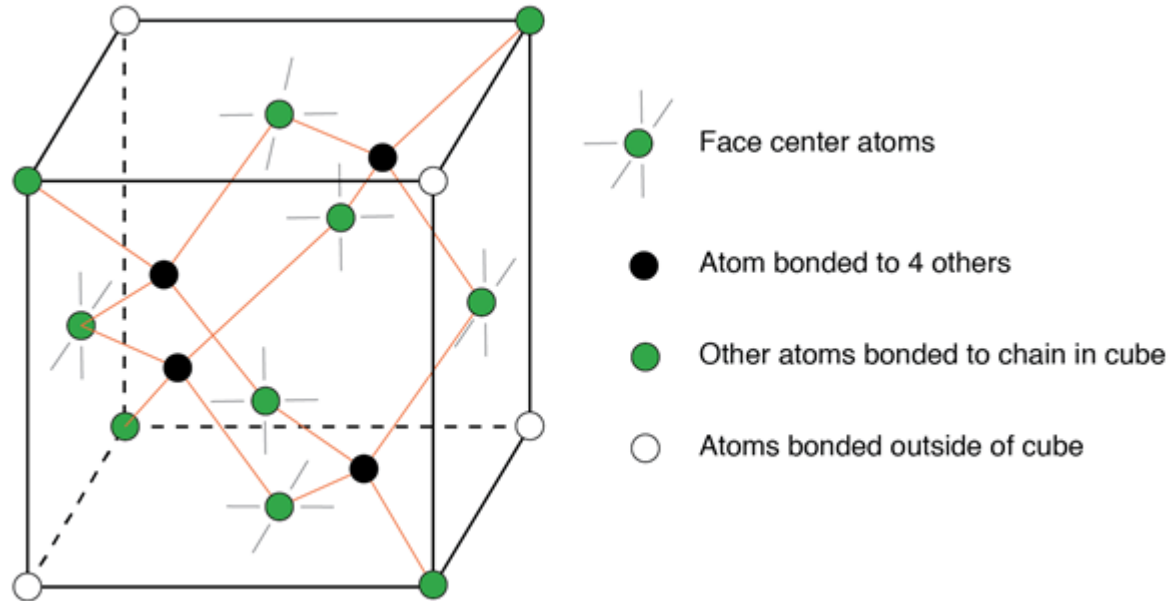


3. Lattice Structure of Semiconductor Materials

- A single unit cell of the Silicon crystal structure (side length, $a = 0.54 \text{ nm}$)



3. Lattice Structure of Semiconductor Materials

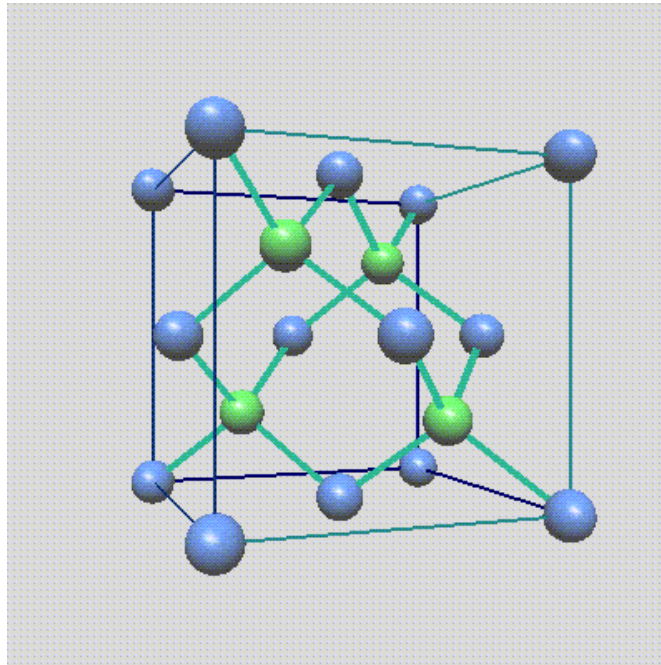


- To calculate number of atoms in a cell of the Silicon crystal structure:
 - $\frac{1}{8}$ of 8 atoms on the corners = 1 atom.
 - $\frac{1}{2}$ of 6 atoms on the faces (sides) = 3 atoms.
 - 1 of 4 atoms inside the crystal = 4 atoms.

Example for Tutorial 2:

1. Determine the number of atoms in a unit cell of GaAs crystal as shown below. Calculate the number of Ga and As atoms in the lattice for 1 cm^3 of material (note that length of each side of the unit cell is 1.2 nm).

[10 marks]



- To calculate number of atoms in a given Silicon materials:
 - No of atoms in a cell = corner + side + center = 4 + 3 + 1.
 - No of cells in 1 cm³ of Silicon crystal materials:

$$\text{No of cell} = \frac{1}{(a)^3}$$

- No of atoms in the 1 cm³ Silicon materials:

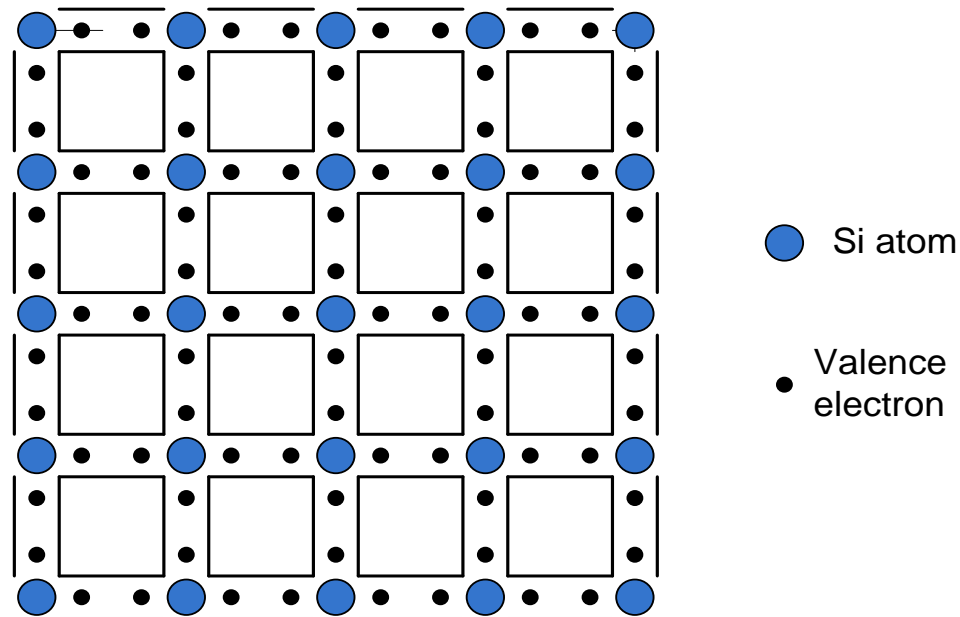
$$\text{No of atoms} = (\text{no of atoms in a cell})(\text{no of cell})$$

Or

$$\text{No of atoms} = (4 + 3 + 1) \frac{1}{(0.54 \times 10^{-9})^3}$$

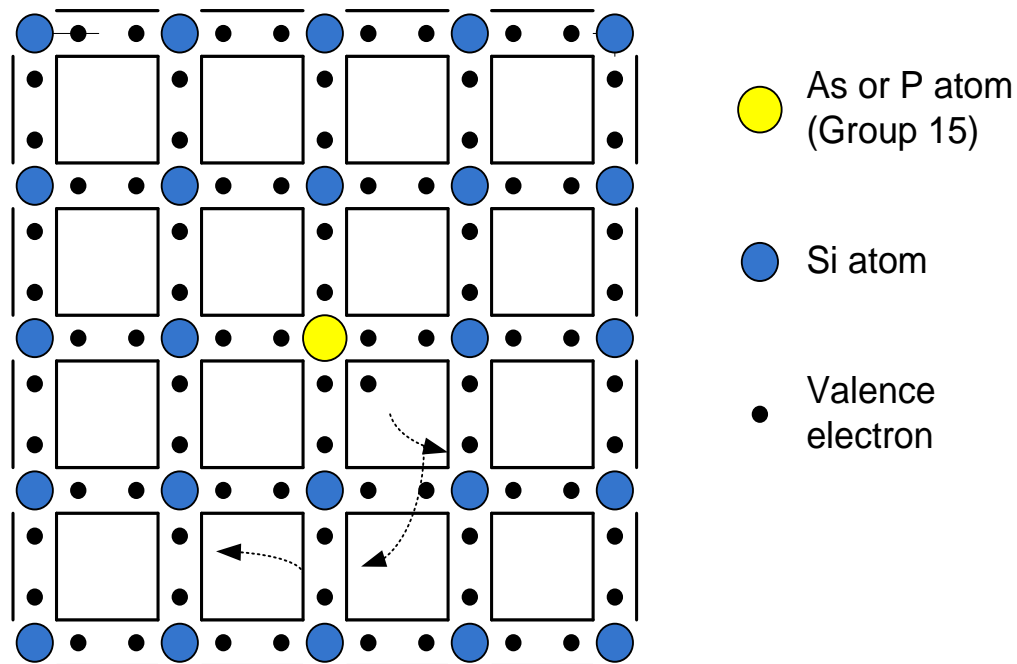
4. Doping of Semiconductor Materials

- Doping means adding other material (dopant) into a pure semiconductor material.
- Its purpose is to change and enhance the property of the semiconductor material.
- A 2D representation of the (intrinsic) Si structure.



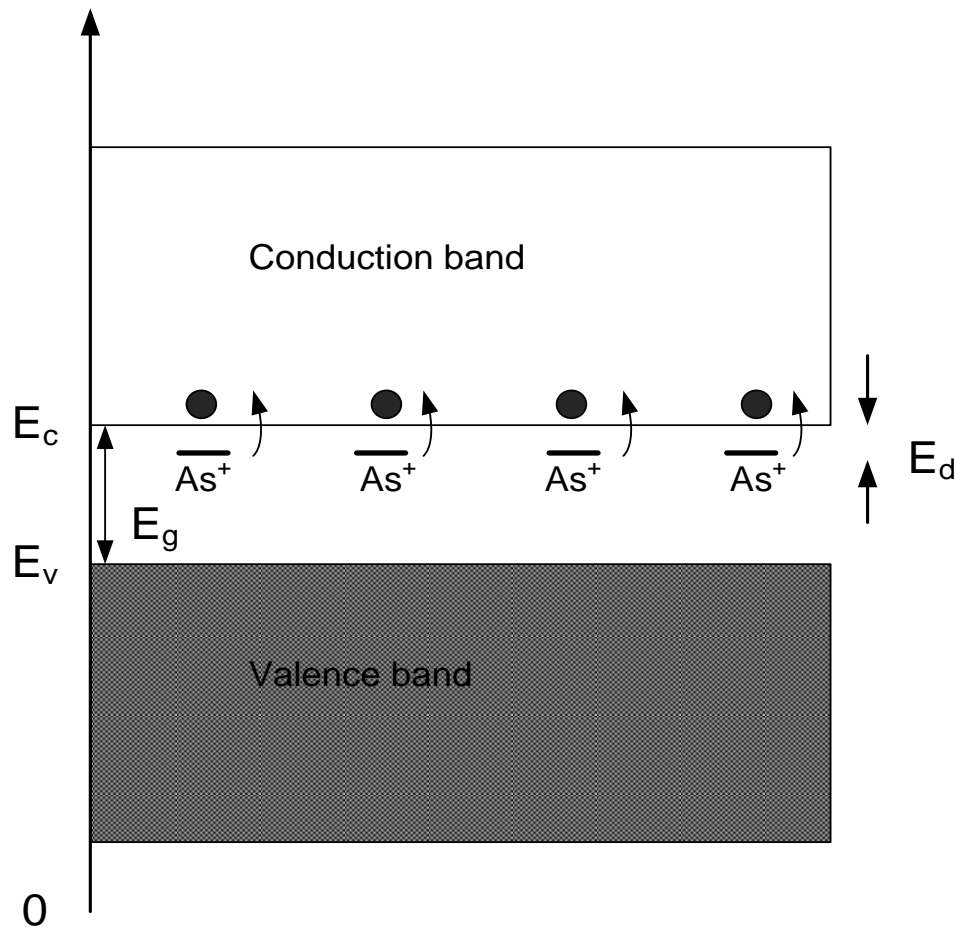
4. Doping of Semiconductor Materials

- A 2D representation of the Si lattice containing n –type dopant (As or P) e.g. Group 15 atoms.
- Doping atoms introduce extra electrons in the structure.



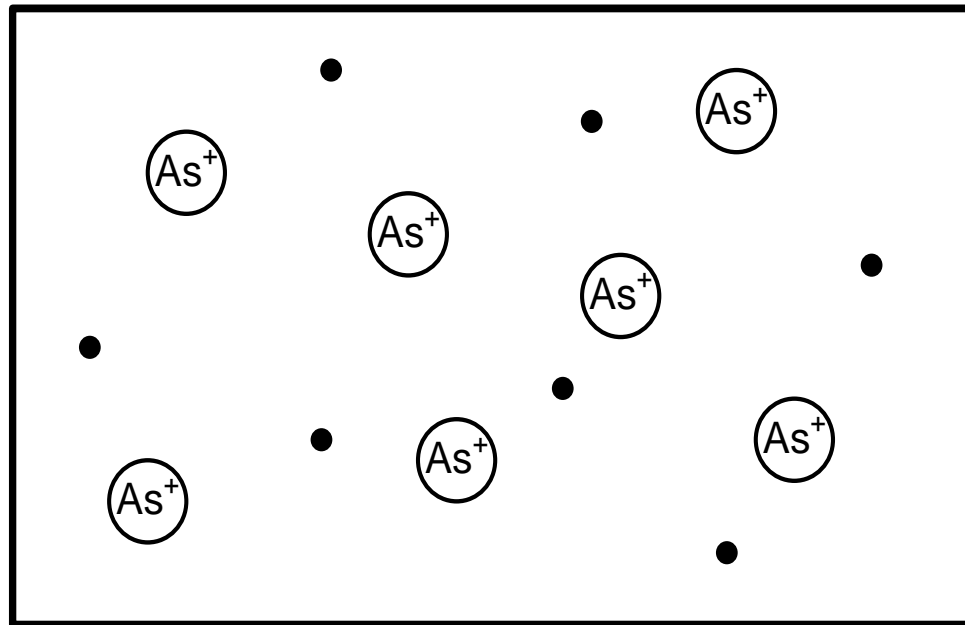
4. Doping of Semiconductor Materials

- The band structure of a n-type semiconductor.
- Electrons are present in the conduction band.



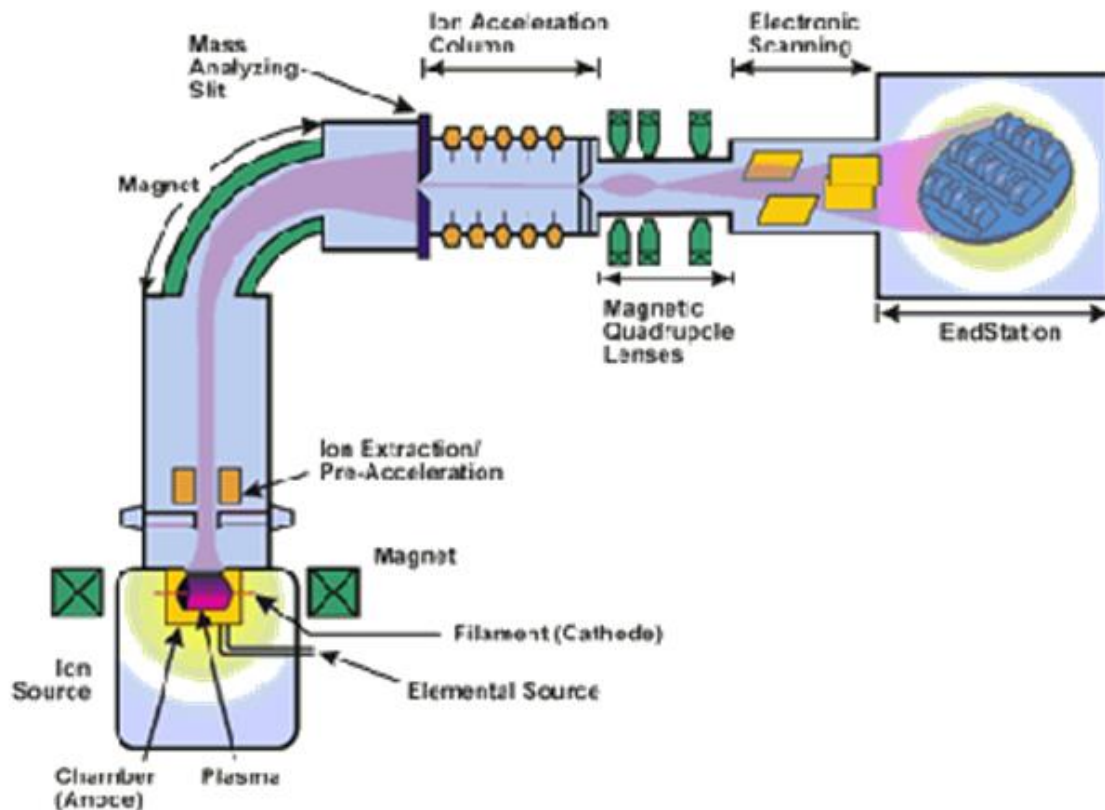
4. Doping of Semiconductor Materials

- Representation of a silicon lattice containing a n-type dopant.
- Note the extra electrons floating around.



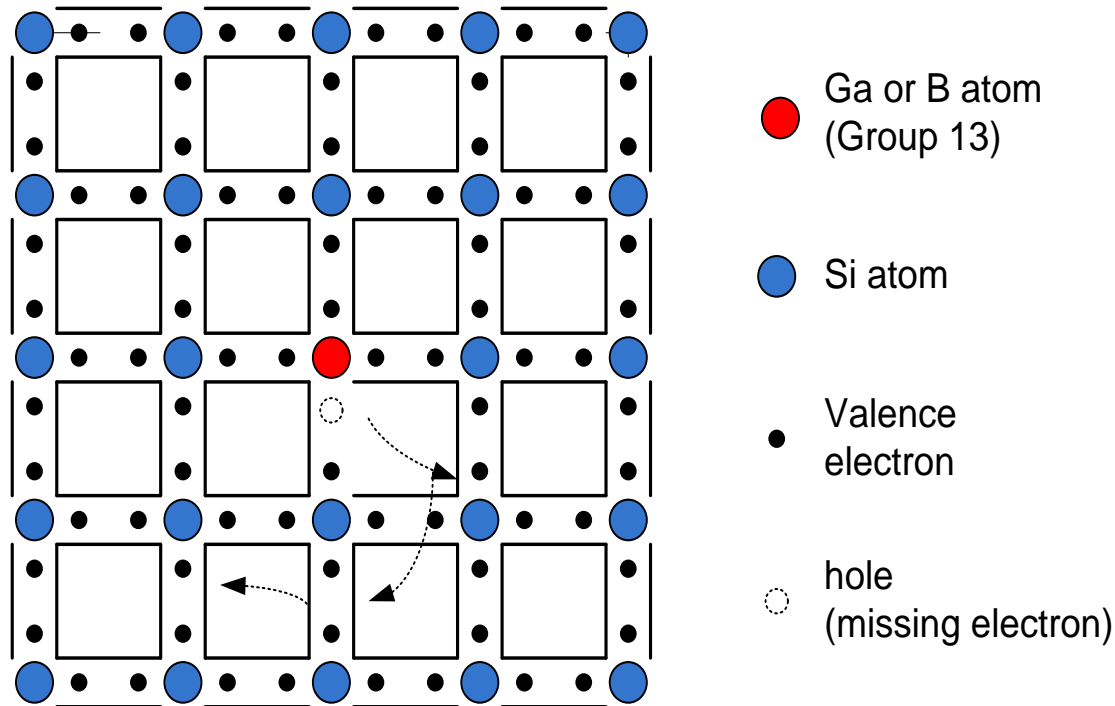
4. Doping of Semiconductor Materials

- In practice, doping atoms is to accelerate and deposit impurities (e.g. other atoms or dopants) into the semiconductor material structure.



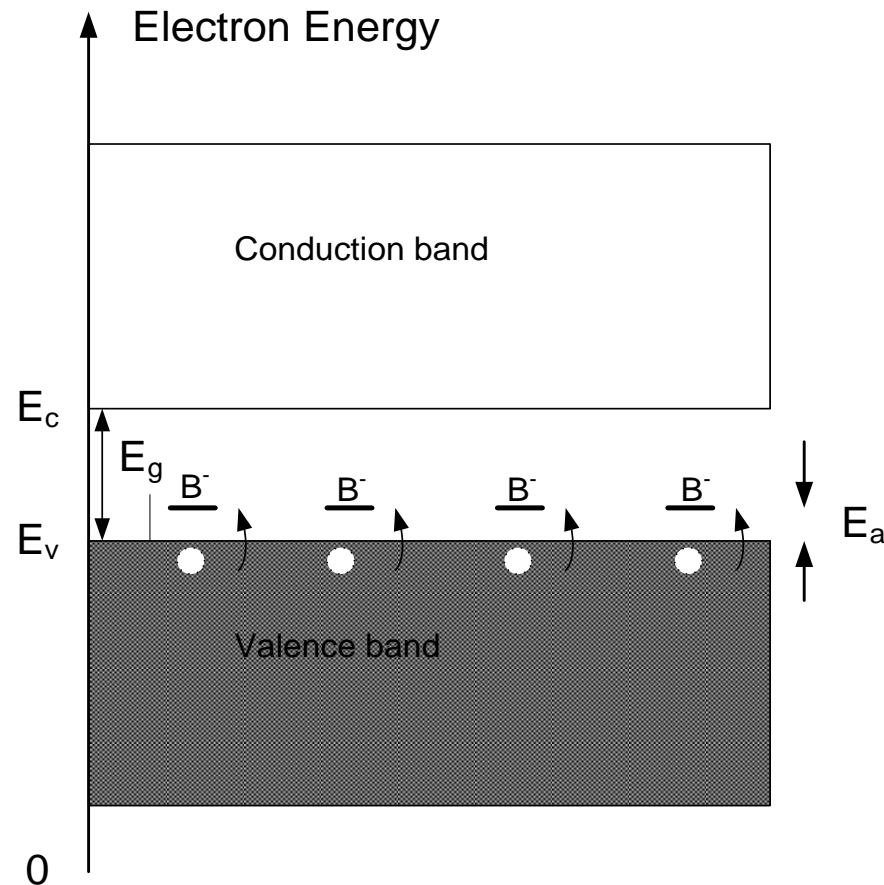
4. Doping of Semiconductor Materials

- The effect of adding an element from Group 13 into the Si lattice i.e. Ga or B.
- Doping atoms introduce holes in the structure.



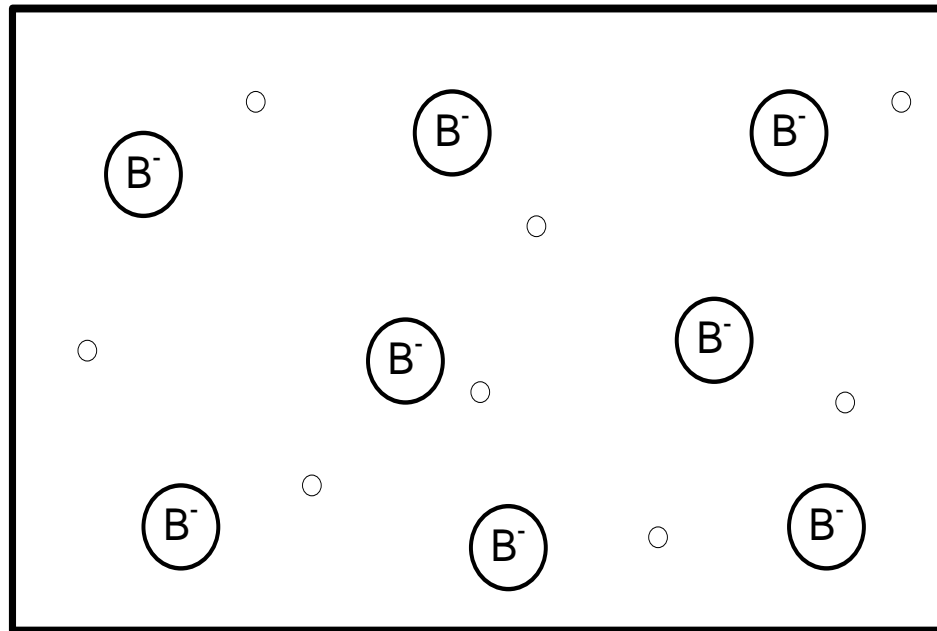
4. Doping of Semiconductor Materials

- Energy band diagram of p-doped silicon.
- Holes are present in the valence band.



4. Doping of Semiconductor Materials

- Representation of a silicon lattice containing a p-type dopant.
- Note the present of holes in the structure.



4. Doping of Semiconductor Materials

- To accommodate the influence of both types of carriers on the conductivity, it is calculated from:

$$\sigma = ne\mu_e + pe\mu_h$$

Where:

- n is the electron density and μ_e is the electron mobility.
 - e is the electrical charge (1.6×10^{-19} C).
 - p is the hole density and μ_h is the hole mobility.
-
- Both carriers contribute to the conductivity and current that flow e.g. the electron and hole current do not cancel each other out, but they add to the total current observed.

Example for Tutorial 3:

1. Calculate the conductivity of a Silicon material if it has intrinsic carrier concentration 1.5×10^{16} per m^3 and the mobilities of the electron and hole are $0.15 \text{ m}^2/\text{Vs}$ and $0.05 \text{ m}^2/\text{Vs}$ respectively.

[2.5 marks]

Conductivity of the material, σ is calculated from:

$$\sigma = ne\mu$$

Assuming the mobility of the particles in the materials are due to electrons and holes, then the overall mobility is:

$$\mu = \mu_e + \mu_h$$

Putting in the values into the equation:

$$\begin{aligned}\sigma &= (1.5 \times 10^{16})(1.602 \times 10^{-19})(0.15 + 0.05) \\ &= 4.81 \times 10^{-4} \text{ S/m}\end{aligned}$$